TRANSACTIONS OF
THE
OPTICAL SOCIETY

VOL. XXI. 1919-20 No. 3.

THE SURFACE LAYER OF AN OPTICAL POLISHING TOOL

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MS. received, 5th November, 1919. *Read and discussed, 12th February,* 1920

THE purpose of this brief note is to suggest that in the later operating stage the surface layer of a pitch, wax, or kindred polishing tool is a continuous layer of glass.

Throughout the polishing process there is a continuous and regular removal of glass. This can be demonstrated by direct micrometer measurement if the operation is continued long enough. Measurement by weight is unsatisfactory owing to the possibility of large errors arising from chipping. Minute particles of the amorphous glass surface layer are removed by a ploughing and swaging action. The individual particles are so minute that their form cannot be resolved by the microscope. When the material removed in the polishing process is collected and all resinous material and rouge is extracted, there is obtained a snow-white residue of glass. Under the microscope this residue has a concretionary appearance, each particle being capable of being broken down into very minute elements.

The ease with which glass in a nascent condition can be welded is well known. Disrupted particles of glass tend to stick together like sugar candy. This is very evident under the microscope. Welding appears to take place at the sharp edges during the momentary formation of the amorphous layer. A mass of fine blown glass may be compacted by pressure. Heat facilitates the action.

Now what becomes of the glass removed during the polishing process? Is it worked out into the grooves of the polisher, or do the particles weld themselves together to form a continuous layer over the pitch surface as I believe at least a proportion of them do?

If a pitch polisher that has been well worked down is examined, the appearance is strongly suggestive of a transparent layer overlying a pitch surface containing rouge or other abrasive. Personally I regard rouge or kindred materials such as

alumina and charcoal merely as abrasives, the function of which is to work the pitch polisher down into true and near contact with the glass surface, the proper final polishing medium being a very thin continuous layer of liquid.

Two polishers of the finest Burgundy pitch were prepared. One of these was left untouched. The other was used as a polisher in the ordinary manner with the exception that water only was used as a polishing medium. No rouge or other abrasive was used at any stage of the operation. The surface was not grooved or reticulated in any way. Polishing was continued for a week in order to accumulate a good layer of glass. Attempts to scrape off the surface and extract the glass gave negative results, the proportion of glass being too small.

It was realised that measurements of the polarising angle would be of no assistance as the refractive indexes of glass and pitch are practically the same. Chemical examination was accordingly resorted to. The surface of the unused polisher was first examined under the microscope. When hydrofluoric acid was applied to the surface there was no reaction whatever. The used polisher was then placed under the microscope and a portion of the surface particularly free from any sleek or other markings was selected. When hydrofluoric acid was applied a copious and long continued evolution of gas over the whole surface occurred. When the focussing gear was racked up, beautiful white spheres were observed floating about in the air, and rebounding from dried up portions of the polished surface. Presumably the hydrofluoric acid had dissolved the glass layer with the formation of bubbles of silicon fluoride gas. This gas readily absorbs water with the formation of a white substance, hydrated silica. Therefore in this passage through the liquid, or possibly in contact with the moisture of the air, the bubbles of gas become coated with a white crust enclosing the remaining gas.

The conclusion is that in the final stage the polishing of glass is principally due to the action of a very thin uniform layer of water between two uniform flat glass surfaces.

DISCUSSION

Mr H. Dennis Taylor communicated the following remarks:

I am afraid I feel obliged to differ from the conclusions arrived at by Mr French in his paper on the action in glass polishing processes.

While it is often true that the rubbing surfaces show signs of being glazed over as described in his fifth paragraph, yet when he speaks of the function of the abrasives being to work the pitch polisher down into true and near contact with the glass surface, the proper final polishing medium being a very thin continuous layer of liquid, I am afraid that these statements are not at all borne out by our experience in these workshops especially in connection with superfine figuring of large optical surfaces, such as those of large telescope objectives, etc.

We always find that the pitch fits itself to the surface being polished by a process of simple subsidence under pressure, while if the pitch is of the right quality and degree of softness the rouge imbeds itself in the pitch surface in contact with the glass just as any hard abrasive powder always imbeds itself in the comparatively

soft metal of the grinder. The latter acts as a matrix holding a layer of abrasive powder, which therefore acts as a sort of file surface upon the harder glass, just as in diamond charged saws or laps the diamond dust is held superficially imbedded in the soft brass or copper, while the harder glass undergoing milling gets all the filing down.

In fact, the general principle seems to be that when two surfaces of different hardness are rubbed together with a still harder abrasive powder between them, then the latter imbeds itself in the softer material while the harder material gets nearly all the abrasion.

Consistently with this hypothesis we find that if the rouge imbeds itself thoroughly in the pitch surface where it touches the glass, so that the said surface appears of a rich rouge red, *not* glazy when dry but of a matt surface, then we always know that both the polishing and figuring are going on satisfactorily. In hand polishing the sweetness and evenness of the frictional resistance is then most noticeable, whereas if the pitch surfaces in contact with the glass appear to be glazy in appearance when the polisher is dry, we know that the polishing and figuring are not going on satisfactorily; we then expect trouble and generally get it. In the case of hand polishing a polisher in this condition is apt to suck and only move in jerks. Still worse is it when the pitch surface in contact with the glass refuses the rouge and shows a black glazy appearance; then we usually get the glass covered with very fine scrubs while it refuses to take a good figure. In hand polishing this sort of polisher clings hard to the glass and can only be moved by strong jerks.

Sometimes we find that tiny pockets, no larger than a pin head, of a white appearance develop in the polisher surface. These would seem to be local accumulations of glass detritus and their presence always causes fine scrubs to appear, therefore we always cut them out whenever noticed.

I do not doubt the fact that glass detritus as well as the rouge plays some part in polishing, but only when it is, like the rouge, imbedded in the surface of the pitch and acting like a file of ultra fineness upon the glass surface being polished. Whether a ground surface or a polished surface results is surely a matter of the degree of fineness of the abrasive particles, which doubtless in the case of polishing are commensurate in size to the molecules of the substance whose surface is being polished, or at any rate are smaller than light waves that are regularly reflected.

The Research Department of Messrs Taylor, Taylor and Hobson, Ltd. communicated the following remarks:

It is recognised that, in the polishing of an ordinary piece of glass, a thickness of about 1/10,000 inch is commonly removed, and it is also true that the surface of a pitch polisher frequently suggests a surface glaze, which might certainly be a thin layer of glass. It is, however, recognised by the author that it might equally well be a layer of polished pitch.

Recently we have been working at somewhat similar problems in these Works, and, since receiving a copy of the present paper, we have repeated the hydrofluoric microchemical test on an ordinary shop polisher. The effervescence shows the presence of a great number of exceedingly minute particles (of glass) imbedded in

the polisher, but they do not appear to form by any means a continuous layer. If, in the case of a flint glass containing lead, a small spot of HCl solution be placed in the field of the microscope, and then there be added a spot of HF, immediately there commence to grow long acicular crystals of lead chloride, having much the same appearance as crystals of calcium fluosilicate. This test is exceedingly delicate and sharp for even very minute particles of the glass. We have not, however, been able to obtain a single passable crystal from the etching in this fashion of shop polishers that have been used on the flint glasses in question, and so consider that the amount of glass present in the polisher (as used in this Shop) is extremely small.

Further, if the surface consisted of a glazed film of glass welded together, the pitch being covered over completely, then organic solvents would not give any reaction. If a spot of benzene be placed on a polished glass surface it immediately begins to contract, and in a few seconds evaporates completely. Placed on a clean surface of pitch it instantly spreads and goes into solution with the pitch, leaving a slight rim to mark the extent of its spreading. Placed on a glazed-looking pitch polisher, the benzene behaves exactly as on clean pitch, and in no way as on glass. If the process be watched under the microscope, there is just time to observe the turbid swirling of the pitch dissolving in the benzene before the latter disappears. With solvent naphtha the same thing happens, but there is possibly a little longer time to observe it.

This seems to show that the greater part of the surface of a polisher consists of polished pitch, in which there is imbedded a small amount of abrasive and a little glass debris*. There is probably no satisfactory microchemical test for the presence of the abrasive, but in the case of rouge the evidence of the colour is sufficient.

Mr P. F. Everitt said he agreed with Mr Dennis Taylor's view of the subject. In working with a hand machine he had found that the maximum pull between the polisher and the glass was obtained when very little free rouge was present and the polisher was fully charged.

He would like to know how long the author took to get a polish comparable with that obtained by other methods. He thought Mr French's theory was very interesting, but he did not agree that the method was an economical one.

Mr T. F. Connolly pointed out the striking difference between the author's theory and the views expressed by Mr Dennis Taylor. According to the former, polishing is largely a phenomenon of surface flow, while according to the latter it is a case of abrasive action carried down to molecular dimensions.

The author communicated the following reply:

I am very pleased that the subject of the glaze on polishing tools has been so fully discussed by the members. In writing the Note, it should be observed that I only suggest the existence of the continuous layer of glass, because I realise how difficult it is to advance any definite proofs. It may be interesting to supplement the original Note by defining more particularly the conditions upon which my experience is based.

* It may be that a polisher worked for a week without grooving or abrasive would not give the same reactions to organic solvents; we have not tried it.

The blocks very extensively used by us have a diameter of 34 ins. and an area, therefore, of about 900 sq. ins. Of this from 75 per cent. to 80 per cent. is glass surface to be operated upon. If the smoothing is good and if the flatness of the pitch polisher is equally good, it is possible to obtain the finest quality of surface by spreading rouge and water over the surface of the tool and then, by means of compressed air, injecting water only for a period of half an hour to one hour, the sequence of operations, rouge and water, being repeated as required until all pits in the surface have been removed. The number of repetitions depends, I believe, upon the initial accuracy of the smoothing and flatness of the tool. From this I conclude that the primary action of the rouge is akin to that of an abrasive. It removes the material and thus lowers the surface to the bottom of the pits.

The very thin film of water acts, I think, by agitating the surface molecules to such an extent that they can rearrange themselves to form a surface akin to that of a liquid. It is possible that, if a pitch surface could be brought into actual contact with the glass without any possibility of the surfaces welding together, the glass would be polished perhaps more rapidly. On the other hand, the danger of allowing the pitch to seize is well known and the conclusion is, therefore, that there must be a continuous layer of moisture between the surfaces. It is well known also that, in the last stage when the moisture is practically dried up, the polishing effect is very great, but even under these conditions there must be a fine film of water. The only conclusion is that it is this very fine film of water that transmits the forces that agitate the surface molecules.

Suppose the polishing action were due to the effect of the rouge. A microscopic examination of the surface in the initial stage a few minutes after the rouge has been applied shows that the rouge is not spread in a uniform film over the surface. It comprises a multitude of round particles akin to snowballs, due to the accumulation or coagulation of the very minute particles of rouge. Is it conceivable that a surface akin to that of a liquid could be produced by even a multitude of such points, the function of which, I think, is to plough or swage minute grooves in the β or amorphous layer and thus remove material? The production of a polished surface akin to that of a liquid seems to me to be directly associated with a continuous medium such as water, not a discontinuous layer such as a pitch layer covered with granules of rouge.

I quite agree with what Mr Dennis Taylor says regarding the pitch fitting itself to large surfaces being polished by a process of simple subsidence under pressure. The amount of subsidence naturally depends upon the particular composition of pitch being used.

I do not suggest that a layer of glass on the polisher is a desirable feature under all circumstances. For example, if it is desired to remove material by the rouge, as, say, when the pits in the glass are unduly deep or the surface irregular owing to defective smoothing, then we find it necessary actually to scrape away the glaze so that the particles of rouge will get a good grip upon the pitch and have a greater swaging or ploughing action.

It seems to me that Mr Dennis Taylor is advocating the rouge theory of the

polishing of glass propounded by Sir Isaac Newton and maintained on his excellent authority, with perhaps the exception of Dr Hook, until Lord Rayleigh suggested the surface flow of glass theory that has been so fully elaborated, particularly in the case of metals, by Sir George Beilby. Personally I prefer the more modern theory and it is on that theory that I have based my suggestion.

The experiments carried out by Messrs Taylor, Taylor and Hobson, Ltd. were practically those which I made in the first instance. Indeed, from these results I doubted very much whether there was any continuous layer or not, and it was only subsequent experience that led me to alter my opinion. That the glazed surface, when liquids are put upon it, behaves like the unglazed pitch surface is, I think, what one would expect. In speaking of a continuous glass surface, it must be remembered that the thickness is probably of the order, at most, of a few wave lengths. But the pitch polisher itself is not free from local irregularities to this extent. Therefore one would expect the thickness of the surface to be variable to the extent of a wave length or two and in places the pitch actually may not be covered. To speak of a continuous layer does not say that the continuity exists over the whole surface. I merely suggest that there are areas of glass with accidental pitch spaces, like numerous small islands in the sea. One would expect, therefore, that the resinous exudations from these exposed patches would contaminate the glass surface which cannot be regarded, therefore, as being a clean surface. Again, if a drop of certain liquids is placed upon an unstable glass film of this kind having so small a thickness, its disintegration is almost inevitable. I came to the conclusion, therefore, that such liquid tests were not reliable. The point I wish to make is that the solid surface of a block of glass cannot be compared with the thin and discontinuous film on the surface of pitch.

In reply to Mr Everett, it is very difficult to compare times of polishing as he suggests, because the time of polishing really depends upon the time and care expended on the smoothing and upon the condition of the tools. I hope some day, however, that I may have an opportunity of putting before the members the results of experiments with a large variety of materials under various conditions. For the 34-inch diameter tool, under the conditions of working described, four hours is a good average time for the polishing operations subsequent to the smoothing process.

Mr Everett's statement that, in working with a hand machine, he found that the maximum pull between the polisher and the glass was obtained when very little free rouge was present and the polisher was fully charged, is no doubt correct so far as the conditions of the experiment are concerned. It all depends upon the amount of abrasion that was required, as compared with the actual polish on the surface flow theory. I think Mr Everett, however, will agree that, if the glass surface were perfectly true and the pitch polisher surface were perfectly free from irregularities, and if there were no liquid layer, then he would have the whole atmospheric pressure upon the surface of the tool and it would be impossible to pull them apart without fracture.

I do not think Mr Connolly's remarks call for any reply. I think he has stated the position correctly from my point of view.

DIFFRACTION PATTERNS IN THE PRESENCE OF SPHERICAL ABERRATION

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MS. received, 8th January, 1920. *Read and discussed, 12th February*, 1920

Introduction

A very well known test for spherical aberration in telescope objectives consists in observation of the image of a real or artificial star of which the angular diameter is too small for resolution by the telescope. In an objective free from aberration the focussed image shows clearly the well-known central disc surrounded by bright and dark rings.

More sensitive than the focussed image, however, as a test for spherical aberration is the appearance of the expanded image in the neighbourhood of the focus. Immediately inside and outside the focus, that is towards and away from the objective, are diffraction ring patterns, the number of rings increasing with the distance from the focus. The symmetry of these ring patterns inside and outside the focus is a valuable guide to the quality of the objective.

With an objective free from aberration the inside and outside focus appearances are almost the same. With an over-corrected objective the ring system outside the focus will be clearer and better defined than that inside the focus. With an under-corrected objective the reverse will be the case. The greater the aberration the greater will be the lack of symmetry.

Object of the Research

The object of this research was to photograph and record the appearance of the images and of the expanded images on each side of the focus of a telescope objective, when there was a known difference of optical path between the marginal and paraxial rays.

Method and Apparatus used

The lens used in the following experiments was a telescope objective consisting of two components—a plano-concave flint glass component and a biconvex crown glass component, the two components being separated by a narrow air-space.

The aperture of the objective was approximately 7·6 cms., and its focal length about 120 cms. The object used was an artificial star at a distance of 14 metres.

The difference of optical path at the focus between the marginal and the

paraxial rays was calculated by the method of trigonometrical ray tracing through the lens, following the formula and methods of Prof. Conrady. Used in the ordinary way with the crown component towards the star the difference of optical path was found to be $\cdot 15\lambda$. This aberration was regarded as negligible and when used in this way the lens is described as having zero aberration. A calculation was then made on the assumption that the lens was turned round so that the light first entered the flint component. The difference of optical path between the marginal and paraxial rays in this case was found to be $+ 3 \cdot 43$ wave lengths.

All these calculations were made for the brightest light—the yellow-green. The calculations were made, using five figure logarithms and check calculations were performed in every case to ensure accuracy. The 4th power law was assumed and calculations were made as to the aperture which would give $\cdot 5$, 1, $1 \cdot 5$, and 2 wave lengths of aberration. Stops were then made to these sizes and the image observed and photographed.

Details of the Apparatus Used

Artificial Star. The artificial star consisted of a diminished image of an electric carbon arc contained in a box. The light from it fell on the eyepiece of a microscope, which gave a diminished image of the crater of the positive carbon. The light then passed through a minus-blue Wratten filter and stops were put at the back lens of the objective and at the point of focus of the image to cut out any stray light.

Telescope Objective. The telescope objective was held in a stand on an optical bench, the adjustments of the stand permitting the lens to be raised or lowered, moved sideways and rotated about a vertical or about an horizontal axis in order to secure correct centering.

Observing Microscope. The image was observed by a microscope having a 1 inch objective and a projection eyepiece. The microscope gave an enlargement of the image on the ground glass screen of a camera box. The magnification of the image on the camera plate was $26 \cdot 5$.

In photographing the image Ilford special rapid panchromatic plates were used. The time of exposure was 3 minutes and the plates were all developed under the same conditions, and with developer from the same stock, for 4 minutes. Photographs were made for the focussed position and for the 2, 3, and 5 ring positions inside and outside the focus for 0, $\cdot 5$, 1, $1 \cdot 5$, and 2 wave lengths difference of path.

The original negatives show more detail, especially in the case of the focussed images, than is exhibited by the prints. The negatives and prints have not been touched up or altered in any way but are the genuine photographic record as taken during the experiments.

Measurements of Diameters of Rings on Photographic Plate. The diameters of the rings on the photographic plates were measured by means of a microscope, with an eyepiece scale when possible. When the contrast of the rings was too poor to permit of the microscope being used a micrometer eyepiece was employed.

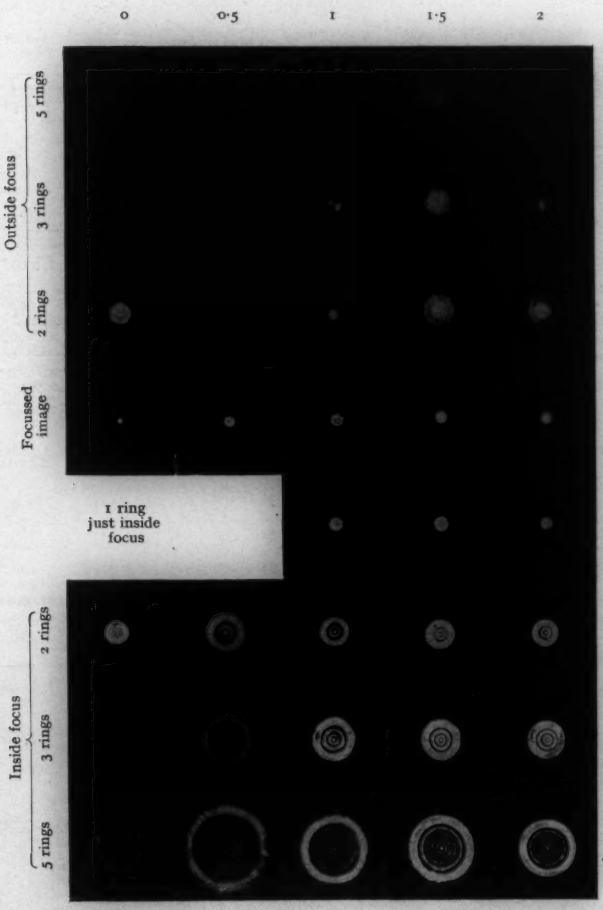

Aberrations in wave-lengths
0
0·5
1
1·5
2
Outside focus
5 rings
3 rings
2 rings
Focussed image
1 ring just inside focus
Inside focus
2 rings
3 rings
5 rings

Fig 1.

Results.

Focussed image. Zero aberration.

No. of Ring	Experimental measurements		Theoretical values for comparison	
	Dark rings	Bright rings	Dark rings	Bright rings
	cms.	cms.	cms.	cms.
1	·0568	—	·0570	—
2	·1	·0773	·105	·0768
3	·145	·118	·152	·126
4	·195	·171	·199	·174

The theoretical values are calculated from the figures given in Chap. 7 of Schuster's *Optics*.

The following tables give the measurements of the out of focus images.

Ring Diameters (2 *rings*)

Aberration		Central disc	1st dark ring	1st light ring	2nd dark ring	2nd light ring	Total diameter
Zero	Inside focus	17	25	42	64	113	204
	Outside focus	29	45	57	79	95	164
·5λ	Inside focus	23	47	87	136	204	332
	Outside focus	12	38	83	128	211	354
1λ	Inside focus	16	30	61	95	170	226
	Outside focus	11	30	72	91	166	207
1·5λ	Inside focus	19	26	57	87	136	223
	Outside focus	11	76	117	134	189	340
2λ	Inside focus	19	23	53	87	134	223
	Outside focus	23	38	64	143	234	340

Unit = 10^{-4} cm.

Ring Diameters (3 *rings*)

Aberration		Central disc	1st dark ring	1st light ring	2nd dark ring	2nd light ring	3rd dark ring	3rd light ring	Total diameter of image
Zero	Inside focus	15	23	42	64	87	113	166	204
	Outside focus	11	23	42	64	87	113	162	200
·5λ	Inside focus	11	38	79	113	158	219	302	400
	Outside focus	11	38	83	113	158	211	279	415
1λ	Inside focus	15	30	60	87	132	170	234	317
	Outside focus	11	45	68	91	143	181	249	302
1·5λ	Inside focus	15	26	57	83	113	155	204	283
	Outside focus	11	26	57	79	113	143	226	294
2λ	Inside focus	19	26	53	79	120	151	208	287
	Outside focus	19	38	57	75	91	121	151	302

Unit = 10^{-4} cm.

Ring Diameters (5 *rings*)

Aberration		Central disc	1st dark ring	1st light ring	2nd dark ring	2nd light ring	3rd dark ring	3rd light ring	4th dark ring	4th light ring	5th dark ring	5th light ring	Outside diameter of image
Zero	Inside focus	11	23	42	64	91	113	143	173	222	245	298	415
	Outside focus	11	23	53	75	90	128	166	—	230	—	317	378
·5λ	Inside focus	11	19	26	90	143	188	234	279	354	430	528	640
	Outside focus	15	23	45	91	120	135	188	226	264	347	453	545
1λ	Inside focus	15	30	53	94	120	166	196	245	294	340	378	491
	Outside focus	8	—	—	38	91	120	181	226	302	347	438	468
1·5λ	Inside focus	15	32	57	94	128	166	188	238	260	276	366	445
	Outside focus	9	19	23	45	83	113	151	230	302	378	423	528
2λ	Inside focus	11	30	53	79	109	139	166	208	238	282	302	408
	Outside focus	8	19	75	—	170	—	264	—	358	—	528	585

Unit = 10^{-4} cm.

Intensity of Light in Rings

In order to make some measurements of the intensity of the light in the rings as recorded by the photographic plate a special comparator apparatus was constructed. This consisted of a microscope having two objective tubes arranged at right angles to each other. By means of a right-angled prism in the focal plane of the positive eyepiece both fields of view could be viewed simultaneously. Half the field as seen through the eyepiece was the field seen through one objective. The other half of the field was that seen through the other objective.

In front of the one objective was placed a photograph of diffraction rings and the particular ring under consideration was focussed. In front of the other objective was placed a standard plate divided into squares, forming a graded series of densities. The objectives used were of $\frac{3}{4}$ in. focal length. A square of the standard plate was found that just matched the central portion of the ring under consideration. The measurements were made for the middle portion, that is the lightest or darkest of the light or dark rings.

Standard Plate

The plate was exposed on an apparatus consisting of a box with, 4 cms. in front of the plate, a sheet of metal pierced by 30 holes of graded sizes. The part of the plate illuminated by one hole was divided from that illuminated by the next hole by a partition of blackened metal. In front of the holes was a stretched sheet of carefully selected grainless paper to diffuse the light. The apparatus was exposed to the sky and rotated during exposure. In this way the plate on development was obtained divided into squares, each square having been evenly illuminated and being of a density which is a function of the area of the hole. The diameters of the holes were carefully measured and the areas were in such a series that, approximately hole 4 had twice the area of hole 1, hole 5 had twice the area of hole 2, etc.

In calculating the results for the intensity curves the area of the hole whose corresponding square gave a match with the central disc of the focussed image was found and the intensity of an area of a ring was taken as proportional to the area of the hole whose corresponding square gave a match with the ring as seen through the comparator—the areas being expressed so that the area of the hole whose corresponding square matched the central disc of the focussed image is taken as 100.

The plate used in making the standard plate and the conditions of its development were similar to those employed in making the series of diffraction ring-pictures with which the standard plate was to be compared. In preparation for some visual observations described in the last paragraph the standard plate was also calibrated against an adjustable sector and the percentage of light transmitted by each square was found.

Intensities (2 *rings*)

Aberration		Central disc	1st dark ring	1st light ring	2nd dark ring	2nd light ring
Zero	Inside focus	27·7	8·8	17·3	6·8	11·3
	Outside focus	22·6	8·8	11·3	8·8	11·3
·5λ	Inside focus	16	3·1	7·7	3·1	7·7
	Outside focus	7·76	3·9	5·1	3·88	5·1
1λ	Inside focus	56·1	·25	14·1	·25	6·8
	Outside focus	6·8	2·16	2·66	·81	·93
1·5λ	Inside focus	43·2	1·28	21·6	2·16	21·6
	Outside focus	17·3	8·5	11·0	6·8	8·5
2λ	Inside focus	50·3	1·15	25·3	3·13	12·6
	Outside focus	25·3	6·1	7·6	6·1	7·6

Intensities (3 *rings*)

Aberration		Central disc	1st dark ring	1st light ring	2nd dark ring	2nd light ring	3rd dark ring	3rd light ring
Zero	Inside focus	3·46	·20	·65	·20	·652	·20	1·02
	Outside focus	5·45	·74	1·36	1·02	1·36	·32	1·02
·5λ	Inside focus	7·74	5·01	6·29	3·85	7·74	3·85	9·92
	Outside focus	7·74	5·01	7·74	5·01	6·29	3·85	7·74
1λ	Inside focus	21·6	·81	8·47	·33	4·32	·33	8·47
	Outside focus	5·31	2·64	3·44	2·64	3·44	·25	·93
1·5λ	Inside focus	17·3	2·64	11	·93	6·8	1·28	6·8
	Outside focus	8·47	5·31	6·8	5·31	5·31	2·16	4·32
2λ	Inside focus	31	1·52	15·5	1·52	7·6	·73	13
	Outside focus	4·8	2·4	2·4	·22	·22	·36	·36

Intensities (5 *rings*)

Aberration		Central disc	1st dark ring	1st light ring	2nd dark ring	2nd light ring	3rd dark ring	3rd light ring	4th dark ring	4th light ring	5th dark ring	5th light ring
Zero	Inside focus	2·11	·47	1·73	·20	·74	·266	1·02	·266	1·02	·266	1·36
	Outside focus	2·11	·47	·74	·47	·74	·47	·74	·47	·47	·47	·74
·5λ	Inside focus	3·85	1·36	3·85	1·36	3·85	1·36	3·85	1·36	3·85	1·36	3·85
	Outside focus	2·47	1·19	2·47	1·36	2·47	·84	2·47	·605	2·47	·605	2·47
1λ	Inside focus	1·69	·25	·81	·25	·81	·25	·58	·25	·93	·25	2·16
	Outside focus	4·15	—	—	—	·415	·40	·415	·33	·40	·25	·33
1·5λ	Inside focus	6·8	·33	4·32	·33	4·32	·33	2·64	·33	2·16	·33	6·8
	Outside focus	2·16	·93	1·69	1·28	1·69	1·28	1·69	1·28	1·69	·398	2·16
2λ	Inside focus	4·8	·83	2·4	·83	2·4	·83	2·4	·37	2·4	·52	4·8
	Outside focus	·73	·52	·83	·73	·73	·37	·37	·37	·37	·36	·37

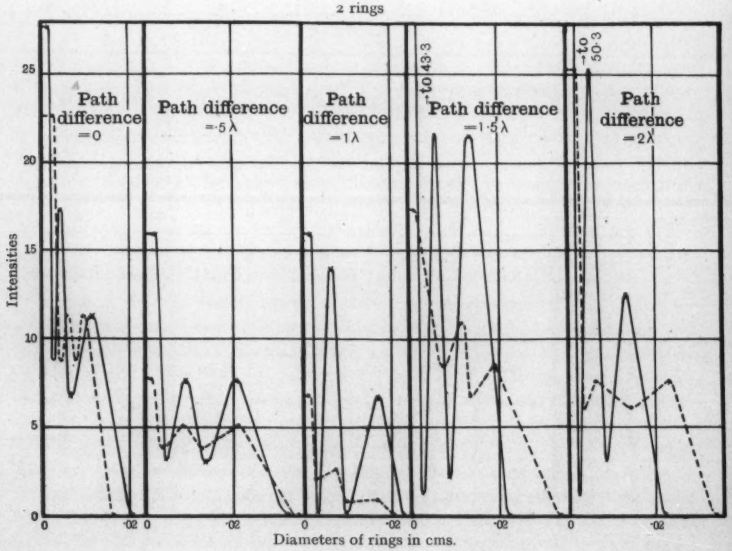


Fig. 2.

In drawing the curves shown in Figs. 2, 3, and 4, the intensity of the light referred to the central disc of the focussed image as 100 is plotted as the ordinate, and the diameter of the ring in cms. is plotted as the abscissa. The continuous

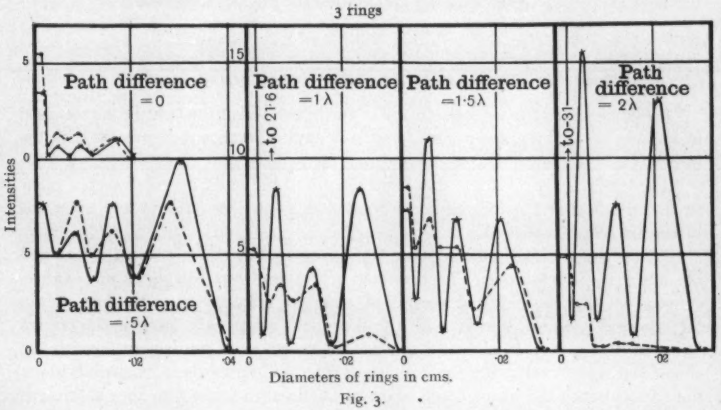


Fig. 3.

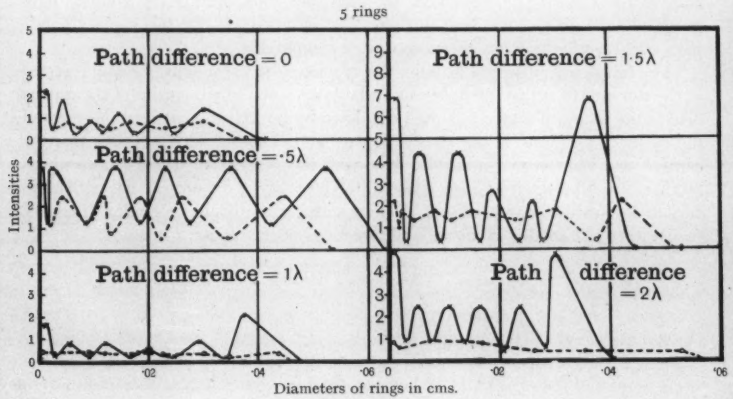


Fig. 4.

curves give the maxima and minima of light inside the position of the focus, that is towards the object glass and the broken curves give the maxima and minima outside the position of the focus. Only the maxima and minima are plotted from measurements. They are joined by a curve to make the diagram clearer, but the

precise slope of the curve between a maximum and the adjoining minimum is without meaning. The curves show clearly the increasing lack of symmetry with increasing aberration and show also how outside the focus with increasing aberration the light is scattered from the ring system into the surrounding field.

Visual Observations on Focussed Image

Visual comparisons were also made of the intensities of the light in the focussed image where ·5, 1, 1·5, and 2 wave lengths of path difference were present with the intensity of the central disc of the focussed image with zero aberration.

The lens was set up in the stand and the pin of the stand provided with a collar so that the lens and holder could be rotated through 180° without any other adjustments being disturbed.

A stop was arranged on a separate stand 6 cms. away and between the lens and the observing microscope. The diameter of the stop was calculated and was so constructed that the required aberration would be obtained when the lens was in the reversed position, that is, with the flint glass component towards the object. On rotating the lens through 180° to place the crown glass component towards the object and slightly adjusting the position of the stand forwards or backwards along the optical bench the image could again be obtained in focus with zero aberration and, as the observing microscope, the stop and consequently the cone of light producing the image were kept unaltered the intensities in the two cases, the one with and the other without aberration, were comparable.

The image was observed through the eyepiece—an extra density being inserted at the star end to adjust the light to a suitable amount. The intensity of the central disc of the focussed image was then cut down by interposing between the eye and the eyepiece a square of the standard plate and choosing such a square that the central disc just became invisible. Knowing the percentage of light transmitted by that particular square a comparison of the intensity of the central disc with some certain amount of aberration and with zero aberration could be made. Measurements were also made for the 1st and 2nd rings of the focussed images.

Aberration	Central disc	1st ring	2nd ring
Zero	1·0	·174	·046
·5λ	·81	·17	—
1λ	·78	·13	·054
1·5λ	·78	·165	·033
2λ	·69	·217	·027

In conclusion I wish to express my indebtedness to Professor Conrady for initiating the research and my thanks to Professors Cheshire and Conrady for kind interest and valuable assistance throughout the work.

DISCUSSION

Mr P. F. Everitt thought that in order to measure the spherical aberration in an objective Hartmann's well-known method would give less trouble and yield more accurate results. He did not quite follow the purpose of Mrs Griffiths' work, as it did not seem to be a case of forming an estimate of the spherical aberration of an objective and then checking the results by other methods.

Mr T. Smith asked in what way the position of focus was determined, and what was the meaning attached to certain errors of phase; did the phase difference refer to the position where the marginal rays met the axial rays?

Mrs Griffiths replied that the position of focus was determined chiefly by appearance; it was thus found separately for each of the stops used. The phase differences were calculated for the marginal focus.

Mr T. Smith, continuing, said it was unfortunate that the positions of focus differed in the various series of photographs. A number of theories were held by different authorities regarding the best position of focus, and each theory involved a different result for the best method of compensating aberrations of different orders. The classical view, in accordance with which the great bulk of calculations were carried out at the present time, considered the paths of the rays only, and correction was directed to bringing all rays within the smallest area on the image plane. According to another view aberrations must be corrected so as to bring the variations of phase in the wave front within the closest limits at the paraxial focus. Professor Conrady had gone further and suggested that the eye would choose as the position of best focus that point where the errors of phase were least. Other theories, as plausible as any of those mentioned, could be brought forward, and these would give still other results. The important fact to bear in mind, however, is that no one can say at present with any certainty what is the correct principle to follow. Any theoretical discrimination must be based on a study of diffraction patterns, and our knowledge of the way in which these should be calculated, though good enough to give the general distribution of light with fair accuracy, is not necessarily sufficiently precise for this much nicer problem. It will be possible to discuss this theoretically when exact solutions have been obtained for the propagation of waves through apertures, but this problem has so far defied solution. There remains the possibility of an experimental investigation, and Mrs Griffiths' photographs might have been of value in this connection had they been referred to a definite focus correlated to, say, the paraxial focus. By comparing photographs and visual impressions with the results of examination by Hartmann's method and with an interferometer test, and by extending such comparisons over a number of objectives of varying focal lengths and apertures and afflicted with differing amounts of aberration, much light should be thrown on this interesting problem.

It was by no means evident that a photograph similar to one of Mrs Griffiths' by another lens would imply that the amount of aberration in the one case could be derived from that known to exist in the other.

Instructor-Commander T. Y. Baker pointed out that the appearance photographed was bound to consist of a combination of the ordinary diffraction patterns with an interference pattern due to the spherical aberration itself. He asked if any attempt had been made to disentangle the two effects.

Mr J. Rheinberg drew attention to the fact that precisely similar patterns can be obtained in a microscope by focussing on a piece of gold leaf having microscopic holes or on a piece of badly platinised glass. With a correctly adjusted microscope, the out of focus diffraction patterns are similar, whether slightly above or below the focus, and when not in correct adjustment the patterns will be dissimilar, corresponding to Mrs Griffiths' observations with the telescope objective. With the microscope, want of adjustment can be introduced at will and controlled by varying the tube length, or altering the correction collar of the objective. The study of these patterns in the microscope under known conditions might therefore be useful as an aid in interpreting the appearances presented by the patterns produced by the telescope objective.

Mr L. C. Martin thought that the scope of Mrs Griffiths' work had been misunderstood. The idea of the research was to give information as to what kind of diffraction patterns could be expected with given path differences. The results obtained, however, agreed with Professor Conrady's theoretical results on the light distribution in the image of a star. The remarkable result is confirmed that for a considerable region outside and inside the position of focus the size of the spurious disc altered very little. Also for considerable amounts of spherical aberration (two or three wave lengths) the size of the spurious disc is not greatly increased, if at all. These conclusions were of great importance in the consideration of the performances of instruments.

(Communicated remarks.) With regard to the position of best focus it seems clear that in this, as in any other type of wave motion, the maximum displacement must be found where the disagreement in phase of the disturbances from all contributing elements is a minimum. There is no reason to think that the eye could select any other region for the brightest light, and experiment leaves no room for doubt that the image appears brightest when the star image is smallest. Physicists must regard the ray conventions for best focus of the mathematician and trigonometrical computer alike as attempts to secure the above condition in a form convenient for calculation.

With regard to the desirability of correlating the chosen focus to that of the paraxial rays it would certainly be interesting to do this if the experimental difficulties of finding the paraxial focus can be overcome, but the position is impossible to calculate from the data of the system owing to constructional errors, and cannot easily be found experimentally owing to the necessity of restricting the aperture of the lens, whereby the depth of focus is greatly increased. Hartmann tests can give no information as to the paraxial focus except by extrapolation from many results, and give no information whatever as to the distribution of light at any point. Hartmann tests are also liable to lend undue weight to the zonal effects of figuring.

With regard to the interpretation of other diffraction patterns than the present

photographs I hope shortly to publish results which will tend to confirm this possibility. For general purposes it seems a common experience amongst those used to testing that aberration may be judged quite effectively from out of focus diffraction patterns and Mrs Griffiths' paper is a first attempt to put the estimation on a definite though approximate basis. It was not intended primarily to check theoretical results.

Prof. Cheshire considered that, even if all that Mrs Griffiths had done was to take the series of beautiful photographs, the paper was a success. Some years ago he had been very much interested in what he thought were direct photographs of star discs in Dennis Taylor's book, *The Adjustment and Testing of Telescopic Objectives*, but upon enquiry he was informed that they had been carefully drawn from observation of the discs.

Mrs Griffiths, in reply to Commander Baker, said she had not attempted to disentangle the two effects to which he had drawn attention.

She was very interested in the microscope analogy Mr Rheinberg had mentioned.

A RAY-PLOTTER

By F. G. SMITH, B.A.

(Communicated by Professor Cheshire.)

MS. received, 10*th February*, 1920. *Read and discussed*, 12*th February*, 1920

The well-known Young's construction is not entirely satisfactory for the use of students; the outer circle is often of an inconveniently large radius; and with more than one refracting surface the series of circles are apt to be confused. With the instrument described below it is unnecessary to draw the auxiliary circles of Young's construction and all the lengths required are already set off for direct

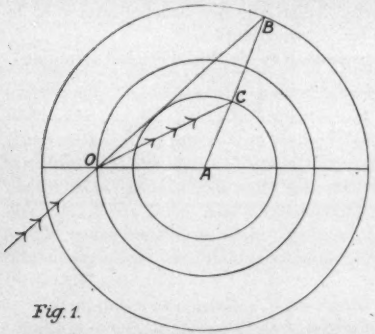


Fig. 1.

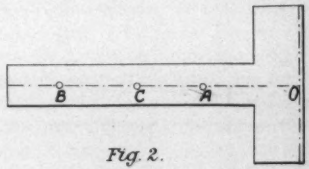


Fig. 2.

transference to the drawing paper; moreover, a single instrument can be used for any desired value of the refractive index n.

Fig. 1 shows Young's construction*, OB being the incident ray produced beyond the point of incidence O to meet the outer circle in B. The join of B to the centre A of the circles cuts the inner circle at C. Then OC is the refracted ray, if the radii of the circles have been taken in the ratios $n : 1 : 1/n$. The usually-given proof will be seen to be true for the point O, whatever the value of the intermediate radius may be.

It is clear that A may be any point on the normal at the point of incidence and still the above construction and proof will hold. Consequently a construction producing a figure similar to that given by the points O, A, B, C and similarly placed with respect to the normal will give the refracted ray. Fig. 2 shows the application to a T-shaped square, made in celluloid or other transparent material, for obtaining the required figure. Points, B, C, A, O are marked on a straight line as shown, AO being taken of any convenient length, say 5 cm., and AB, AC being made equal to $n \,.\, AO$ and $1/n \,.\, AO$ respectively. Placing the instrument so that O is over the point of incidence and the line OA over the normal and using a needle

* See Young's *Lectures on Natural Philosophy*, Vol. 2, Art. 425 (1807).

put through a pivot-hole at A as a centre, we can set the point B on the incident ray (or, if preferred, the ray produced). Then C is a point on the line of the refracted ray. The points B, C are also pierced through for marking and setting off. For rays emergent from a denser medium, the point B is set on the incident ray and C is on the refracted ray. For convenience in explanation only one value of n is shown marked on the instrument; but of course a complete scale of values of n and $1/n$ may be marked out, as by holes at intervals or by scales along the edges or by a scale along a narrow slit cut through the appropriate part of the line AB. In general the line OB is placed along the normal by making it lie over the centre of the refracting surface; but an alternative method is to set the line through O at right angles to OB tangentially to the surface.

Clearly an instrument comprising a graduated arm pivoted at A, Fig. 2, could be designed; and, indeed, a more elaborate instrument, based on the same geometrical construction and consisting of pivoted and sliding rods has, I now find, been described in the *Optician* of 25th May, 1917, on p. 152, Fig. 3. Such constructions, however, are not sufficiently simple to come into general use.

DISCUSSION

Mr T. Smith suggested a modification which would enable all refractive indices to be treated on the one instrument. The greater part of the instrument would be made as proposed, but in place of the two holes used a straight slit would be substituted. A second but smaller transparent plate would be mounted on the first, rotatable, against considerable friction, about the centre of curvature. This second plate would carry two curved slots, approaching one another towards one end and receding from one another at the opposite end. Any relative position of the two plates would correspond to some refractive index, the holes of the original template corresponding to the intersections of the straight slot with the curved slots. The two curves must be the inverses of one another. Thus if one is a circle or a straight line, the other is a circle. The upper plate in which the curved slots were cut would carry a scale of refractive indices.

Professor F. J. Cheshire thought that, whilst Mr T. Smith's suggested modification was a very ingenious one, its adoption would defeat the whole object of the invention, which was to produce a simple, inexpensive ray-plotter for elementary work by elementary students. In the form proposed by Mr F. G. Smith it would have many useful applications in the laboratory.

The author communicated the following reply:

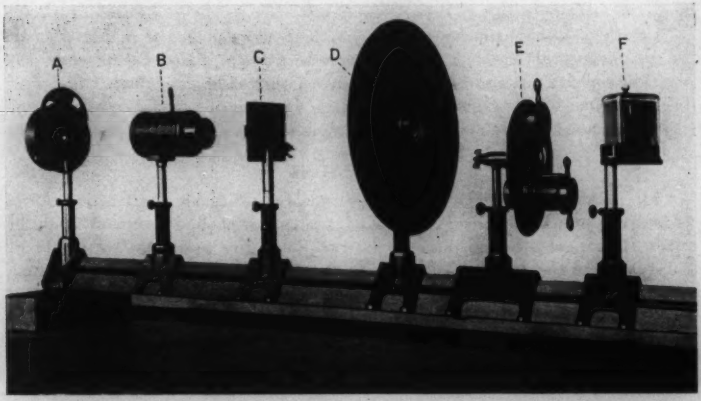
The paper refers to provision for other indices. But it may be pointed out that the values of n and $1/n$ may be set off along *any* radius through O, so that a fairly complete set of values could be provided for by using a number of different radii; the values on any one radius could then be spaced far enough apart to be marked by pin-holes, intermediate values appearing on other radii. Perhaps, however, the best plan would be to construct one's own scale on tracing-cloth whenever a choice of values was required, marking the value actually in use with a pencil. The simple form described, with, say, two values marked, should meet most requirements.

EXHIBIT OF A PROJECTION SPECTROPOLARISCOPE

By Professor F. J. CHESHIRE, C.B.E.

Exhibited, 11th December, 1919

The use of a projection spectropolariscope specially adapted for class and lecture work was described and demonstrated.



The apparatus, as shown by the figure, consists of a triangular metre-bar upon which the necessary fittings are mounted. The fitting *A* consists of a rotatable disc with a number of different-sized holes. The fitting *B* carries a double-image prism which can be rotated through 180°. The end of the prism casing next to the diaphragm *A* is fitted with a lens, the focal plane of which coincides with the diaphragm *A*. A second lens, at the reduced end of the casing, serves to condense the light upon an adjustable slit *C*. This slit is focussed upon the screen by the projection lens *D*, the light passing through a double-image prism, or it may be an analyser *E* and a bottle prism *F*. In use an arc light is focussed by the usual lantern condenser upon a suitable aperture in the disc *A*. In this way the light source becomes virtually a sharply defined circular disc. The collimated beam of light passes through the double-image prism in *B*, one of the resulting beams passing direct along the axis of the instrument, whilst the second beam is deflected through a sufficient angle to throw it out of the apparatus. In virtue of the sharply defined light source there is practically no intrusion of one beam on the other. The direct beam of plane polarised light (vibrations vertical) is focussed upon the slit *C*. When therefore a

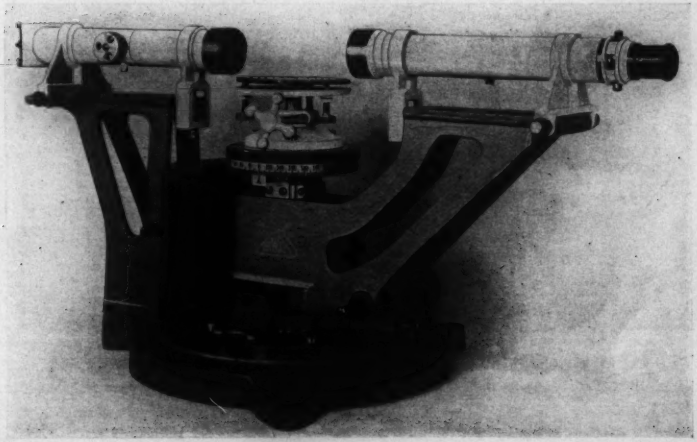
crystal plate, cut parallel to the axis, is placed against the slit with its extinction directions at 45°, and the double-image prism is turned to transmit vertical and horizontal vibrations, two vertically superposed images of the slit are projected upon the screen in the absence of the dispersing prism *F*. In one of these images the light is polarised in a vertical plane whilst in the other the light is polarised in a horizontal plane. When the prism *F* is inserted, these images are drawn out horizontally into spectra, which are seen to be crossed by absorption bands corresponding to the retardation of the plate, one spectrum being complementary to the other. In the case of a plate of axis-cut quartz, the rotation of a Nicol in the fitting *E* results in a spectrum on the screen with dark absorption bands travelling continuously to the right or to the left according as the particular crystal is right- or left-handed. The apparatus lends itself to the performance of a number of very interesting experiments. The placing of the crystal immediately against the slit results in much sharper definition of the bands than is obtained with the more usual apparatus.

EXHIBIT OF A SPECTROMETER, MADE BY MESSRS E. R. WATTS AND SON

By L. C. MARTIN, D.I.C., A.R.C.Sc., B.Sc.

Exhibited, 11th December, 1919

This instrument is designed on lines at once simple and strong. While the present arrangement includes only such parts as are strictly necessary for the performance of the simpler goniometric measurements, yet the construction is such that verniers of greater sensitiveness and telescopes of greater magnifying power could well be



used, and such indeed could be provided if called for. The verniers of the telescope move in the plane of the main divided circle which is fixed to the base, and which is 8 inches in diameter. A smaller divided circle and verniers are provided for the table.

The telescope axis appears to be longer than is usual in the majority of spectrometers and it is well counterbalanced, features which will doubtless make for long wear and freedom from shake.

Both telescope and collimator may be given small altitude and azimuth adjustments on their supports, and these adjustments do not necessitate any deformation of the tubes, a grievous fault of design in many of the inferior instruments of this class. Both telescope and collimator also have rack focussing while the eyepiece

of the telescope has helical focussing with a diopter scale. The slit is of a very simple nature and is easy to clean.

Tested in the Optical Engineering Laboratory of the Imperial College, the instrument has shown itself to be satisfactory as regards the accuracy of construction of circle and verniers, and the optical definition is good; while the design is generally convenient in use. It has been incidentally found that fixed magnifiers for reading the lower circle are desirable, but as the dividing in the present instrument is very clear and easy to read these magnifiers could have a longer focus than usual, thus preventing the usual shadowing of the circle by the head of the observer. No doubt such lenses could be provided very easily by the makers.

Owing to this clearness of dividing of the circles, also to the simplicity and great strength of the design, the instrument is likely to be very useful for teaching purposes. It should also find a sphere of usefulness in the testing laboratory, especially if a micrometer fine adjustment similar to that of the Pulfrich refractometer and to those of certain old Steinheil spectrometers were given to the telescope. Results for the *dispersions* of prisms could then be obtained with an accuracy comparable with that of the value for absolute refractive index—an impossibility when the ordinary vernier measurements are alone possible.

If a more elaborate instrument were desired, micrometer microscopes for the main circle could doubtless be provided, and as was previously indicated, a larger telescope and collimator could easily be carried by the same supports.

This is surely a praiseworthy principle of design that the workmanship of even the simpler types of instrument should be the very best. Any improvements or additions later found to be necessary will not be wasted on the original. The illustration shows one of the earlier trial models. Verniers are now supplied to the table circle in addition to the main circle.

REVIEW

Applied Optics; The Computation of Optical Systems, being the *Handbuch der angewandten Optik* of Dr Adolph Steinheil and Dr Ernest Voit, translated and edited by James Weir French, B.Sc. (2 vols). (Blackie and Sons, Ltd., London and Glasgow, 1918–19. Price 15*s*. each vol.)

This translation of Steinheil and Voit's *Handbook of Applied Optics* is a unique and valuable contribution to the literature of technical optics in all English-speaking countries. It is the first published book, that has appeared in the English language, in which the trigonometrical method of ray-tracing, as opposed to the algebraic method, has been set out with the fullness necessary to meet the wants of the optical designer and computer. When, further, it is remembered that the method set out and explained is that which has been in common use in Germany for the last 50 years, and one too that has been largely used by some of our most important opticians in England, the importance and value of the book, to those concerned with the commercial production of optical systems, will be realised.

Exact ray-tracing through optical systems was first made possible by the discovery of the fixed lines of the solar spectrum by Fraunhofer in 1814–5, with the result that the firm of Steinheil & Sons of Munich introduced trigonometrical ray-tracing into their workshops about the year 1860. At first the method was restricted to ray-tracing in axial planes only; later, however, the general problem was given to von Seidel with the result that he read a paper before the Bavarian Academy of Science on November 10th, 1866, upon "The trigonometrical formulae for the general case of the refraction of light by a system of centered spherical surfaces." In this paper, as will be gathered from its title, von Seidel gave the necessary formulae for ray-tracing in other than axial planes and thus completed the method.

It was the original intention of the authors that the handbook should be completed in three volumes, of which however only one has appeared—that which is now translated. The first of Mr French's volumes includes chapters on the more elementary parts of the subject, such as the reflection and refraction of light, and the fundamental properties of dioptric systems, leading up to the final chapter on "The Computation of a lens and the Discussion of its image aberrations." The second volume deals with the determination of refractive indices, the achromatic double-objective, and finally the aberrations of oblique image points. The original paper of von Seidel is given in the form of an appendix.

Editor and publishers have done their work most admirably. The translation bears evidence of having been done with very great care. The original system of signs and conventions, which had evidently been very carefully worked out, has been substantially adhered to in Mr French's translation; English characters have, however, been substituted for the German characters. The book is printed in good type on excellent paper. The greatest and most valuable novelty, however, in the form of the book is the presentation of the ray diagrams in black, red, and blue lines. This colour differentiation lessens very considerably the difficulty of reading and is an innovation which it is to be hoped will be generally followed by subsequent writers on the subject.

F. J. C.

ABSTRACTS

"A Simple Method for the Approximate Determination of the Secondary Spectrum of an Objective." By E. Hertzsprung. *Astron. Nachr.*, 207 (1918), 87.

The author suggests the use of an objective grating. He determines the position of normal focus, that is, the one which gives the smallest image of a star, and assumes that it corresponds to the turning point of the secondary spectrum. He then places the grating in position and takes a photograph at such a distance outside the focus that in the diffraction spectrum of the first order the light corresponding to a wave-length in the visible spectrum is sharply focussed. Erythrosine-silver plates, sensitive to red light, are used. For the same position of the plate radiation corresponding to a wave-length in the ultra-violet is also sharply focussed. The dispersion image gives rise to two separate nodes depending on these two wave-lengths, whose values can be determined from the distance between the nodes, the distance of the plate from the position of normal focus, and the grating constants. By employing a formula given by J. Hartmann for the focussing of the secondary spectrum the author calculates the wave-length corresponding to minimum focus, that is, the position giving the smallest image of a star. He further determines the positions for other wave-lengths and thus obtains data for the whole course of the secondary spectrum.

In the case of objectives of shorter focal length it is difficult to use a sufficiently fine grating to obtain adequate separations between two different wave-lengths in the spectrum of the first order. The author therefore recommends the use of higher order spectra of a bright star. In order to prevent the nodes of different orders and wave-lengths from falling too close together it is advisable to use gratings in which the thickness of the wires is equal to the breadth of the spaces; in this case the even order spectra vanish. Since great accuracy cannot be obtained, one may use as gratings the fine metal gauzes which are on the market.

As an example of the method the results of measurements on a Zeiss UV. Triplet objective of 150 mm. focal length are given. The wave-length for the minimum position was 394 $\mu\mu$, and at a position 6·6 mm. outside this light corresponding to the wave-lengths 526·4 and 337·9 $\mu\mu$ was sharply focussed.

J. S. A.

"Photo-electric Spectrophotometry by the Null Method." By K. S. Gibson. *Scient. Papers*, Bur. of Stand., No. 349 (1919).

The author points out the fact that the potassium-hydride photo-electric cell gives a maximum response to light in the neighbourhood of 460 $\mu\mu$, and is therefore useful in supplementing visual and photographic measurements of spectral transmission. In his work he employs a null method, since any deflection method, except one of equal deflections, is almost valueless for accurate work unless the relation between the photo-electric current and the exciting radiant power is accurately known for all values of wave-length and radiant power to be used. Another source of trouble in most deflection methods has been the difficulty of eliminating the so-called dark current, that is, the current through the cell when no radiation is falling on it.

The principle of the null method employed is as follows. Two photo-electric cells and batteries are used in a kind of Wheatstone bridge arrangement, an electrometer acting as an indicator of equality between the currents through the two cells. Two sources of light are employed; the light from one of them passes through a monochromatic illuminator before it falls on the corresponding cell. Thus any portion of the visible spectrum may be examined. The intensity of the radiation in this case is varied by altering the distance of the source of light from the first slit of the monochromatic illuminator, use being made of the inverse square law.

Transmission curves were obtained by this method for a number of glass specimens and the accuracy of the measurements was tested by measuring the transmission (1) of rotating sectors of known aperture and (2) of standard samples and other good specimens whose transmission had been obtained by other methods, visual and photographic.

The accuracy of the photo-electric method was found to vary from about 1 per cent. at high transmissions to about 10 per cent. for values of transmission equal to 1 per cent. or less for the range of wave-lengths from 410 to 550 $\mu\mu$; the uncertainty of measurement was somewhat greater in the regions beyond these wave-lengths as far as 390 and 600 $\mu\mu$ inclusive.

The method was also used for measuring diffuse spectral reflection. The author states that it can be applied to the measurement of the relative radiant power of two sources and to the measurement of fluorescence, and further that it could be extended into the ultra-violet if quartz parts were used instead of glass.

J. S. A.

NOTICES

An exhibition of electrical, optical, and other physical apparatus was held by the Physical Society of London and the Optical Society on the 7th and 8th January, 1920, at the Imperial College of Science and Technology.

A Symposium on "The Microscope: its Design, Construction, and Application," was held by the Faraday Society, the Royal Microscopical Society, the Optical Society, and the Photomicrographic Society on 14th January, 1920, at the rooms of the Royal Society, Burlington House.

OBITUARY NOTICE

STEPHEN DRUMMOND CHALMERS, M.A.

It is with very deep regret that we record the death of Mr S. D. Chalmers, a Vice-President and Past President of the Optical Society, on Friday, Nov. 7th, 1919, after a short illness.

Born at Wallsend, near Newcastle, N.S.W. in 1877, he graduated at Sydney University, and, like several other Australian students who have made their mark in the scientific world, subsequently came to Cambridge with a travelling fellowship. He entered St John's College, graduated as a wrangler, and immediately obtained an appointment as lecturer in Mathematics at Owens College, Manchester. A year later he migrated to the Royal Naval College, Greenwich, where he continued until 1903, the date of his appointment as Head of the newly-established Department of Optics of the Northampton Polytechnic Institute in Clerkenwell.

Chalmers' work at this Institute is too well known to members of this Society to need any lengthy appreciation in these transactions. It is not, however, realised by many how greatly he was hampered in his work by the severest restrictions of space and means. The failure, some years before the war, of the L.C.C. to give the necessary support for the erection of the projected building for Optics (for which a site had been purchased by the Institute) was a very heavy blow to him, as he had been no less sanguine that this support would be forthcoming than of the success which would ultimately be achieved. His difficulties were by no means decreased by the want of adequate previous training in many of the students with whom he had to deal. The effect of this is evident in much of his published work. All these conditions together resulted in his work costing an excessive amount of effort, and there can be little doubt that this long continued over driving contributed to his early death. None the less, the Optics Department has a most valuable record, the war work done there being of special importance. This included not only the testing of a large number of optical instruments, but also the training, in a specially equipped workshop, of a large number of girls to become skilled lens grinders and polishers.

Although he wrote many papers, several of which were read before this Society, Chalmers' published investigations represent only a small fraction of the original work he carried out. In part this is attributable to the heavy call upon his time by his work at the Institute, and in part also to a dislike for writing. His mind was so full of new ideas which were constantly clamouring for investigation and trial that work already completed rarely received the attention that its interest warranted. He possessed the faculty of picturing the physical significance of all the mathematical operations he employed and of the results to which they led, and this was doubtless an important factor in the success of his work. Thus, in much of his mathematical work he made no attempt to treat the problem exactly by taking all the factors into

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account, but the conclusions which he reached, though in the nature of the case not exact, will not be found to be seriously in error. As in his mathematical investigations, so in his physical experiments his most remarkable quality was fertility in ideas. This was frequently evident in the course of discussions at meetings of the Society, when he not only made many interesting suggestions for new experiments, but often gave his experience of experiments, sometimes made long before, similar to those described to the meeting. He was splendidly qualified for the post he held, and gave of his best to his students. The rest of us are the poorer in that he was unable to describe his work more freely and fully.

Chalmers was perhaps more continuously associated with the Optical Society as an active member than anyone else. Since 1904 he was a member of its Council, and for a considerable period acted as its Hon. Secretary and Editor of its Transactions. He became President in 1909–10, and presided at the "Thomas Young Oration" delivered that year by Prof. R. W. Wood. As one of the representatives of the Society, he was actively concerned with the formation of the new Institute of Physics. He served on the Council of the Physical Society, and he undertook a large share of the work connected with the Catalogues and the Proceedings of the two Optical Conventions of 1905 and 1912.

He was very regular in his attendance at the meetings of both the Society and of the Council. At the latter his wide knowledge of all branches of optics, of the history of the Society, and of the individual members of the Society proved most valuable. No member of the Society worked harder for its welfare; none can be more greatly missed. His kindly nature and readiness to help in all quarters secured for him a wide circle of friends among our members, by whom his loss is deeply mourned.

W. R.
T. S.